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(54) CONTROL RESET AND DIAGNOSTIC TO MAINTAIN TAILPIPE COMPLIANCE

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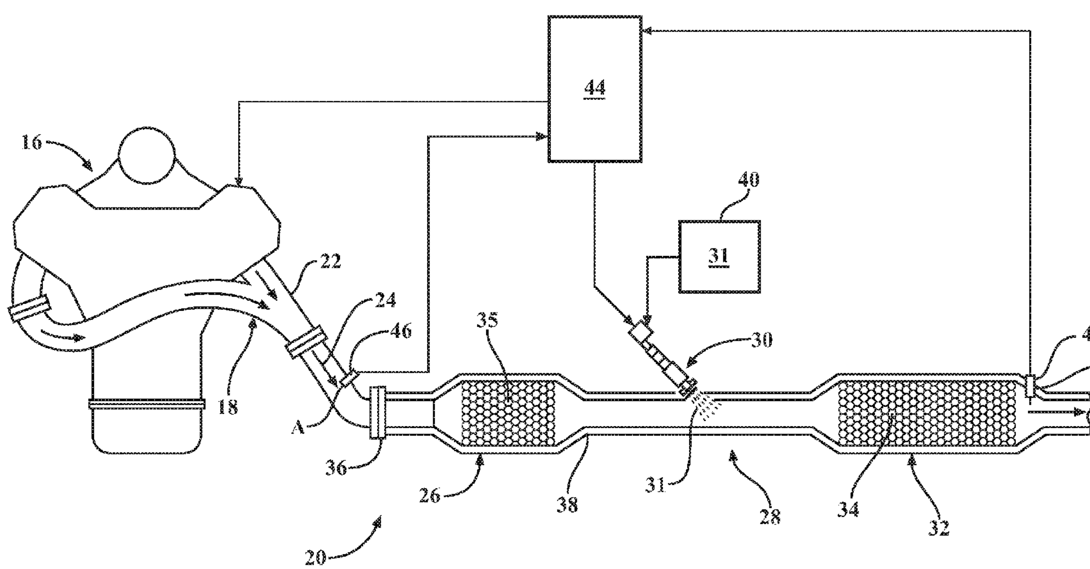
(57) **ABSTRACT**

A method, control system, and vehicle system configured to control a selective catalyst reduction (SCR) system subtracts an amount of NO_x present in a tailpipe upstream of the SCR system from an amount of NO_x present in the tailpipe downstream of the SCR injector. A cumulative difference may be determined based on integrating the subtracted NO_x value. The method, control system, and vehicle system are configured to determine whether the cumulative difference exceeds a control threshold, and to set a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold, but to set the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold. Thus, the system is reset to the model when downstream NO_x values exceed upstream NO_x values above a threshold, to bring the system back within control.



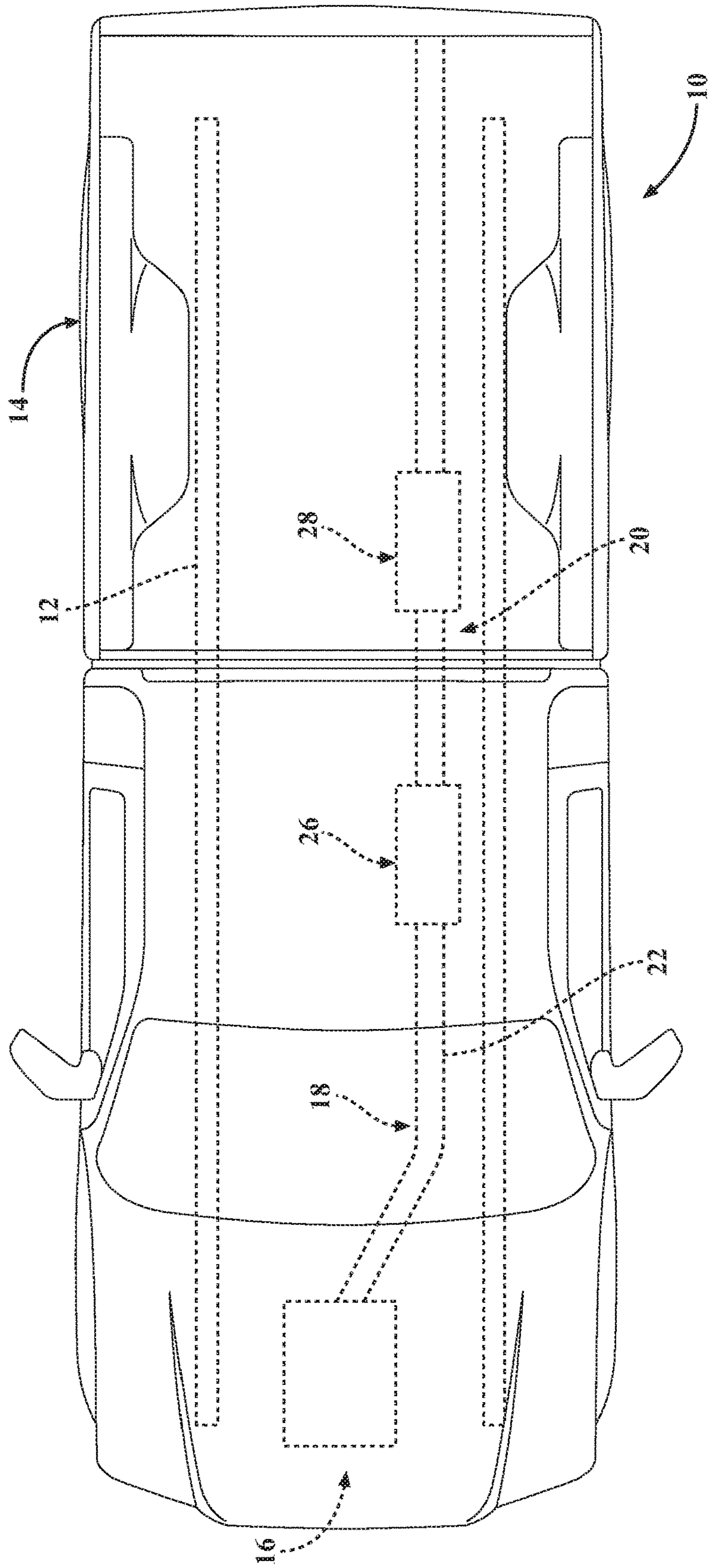


FIG. 1

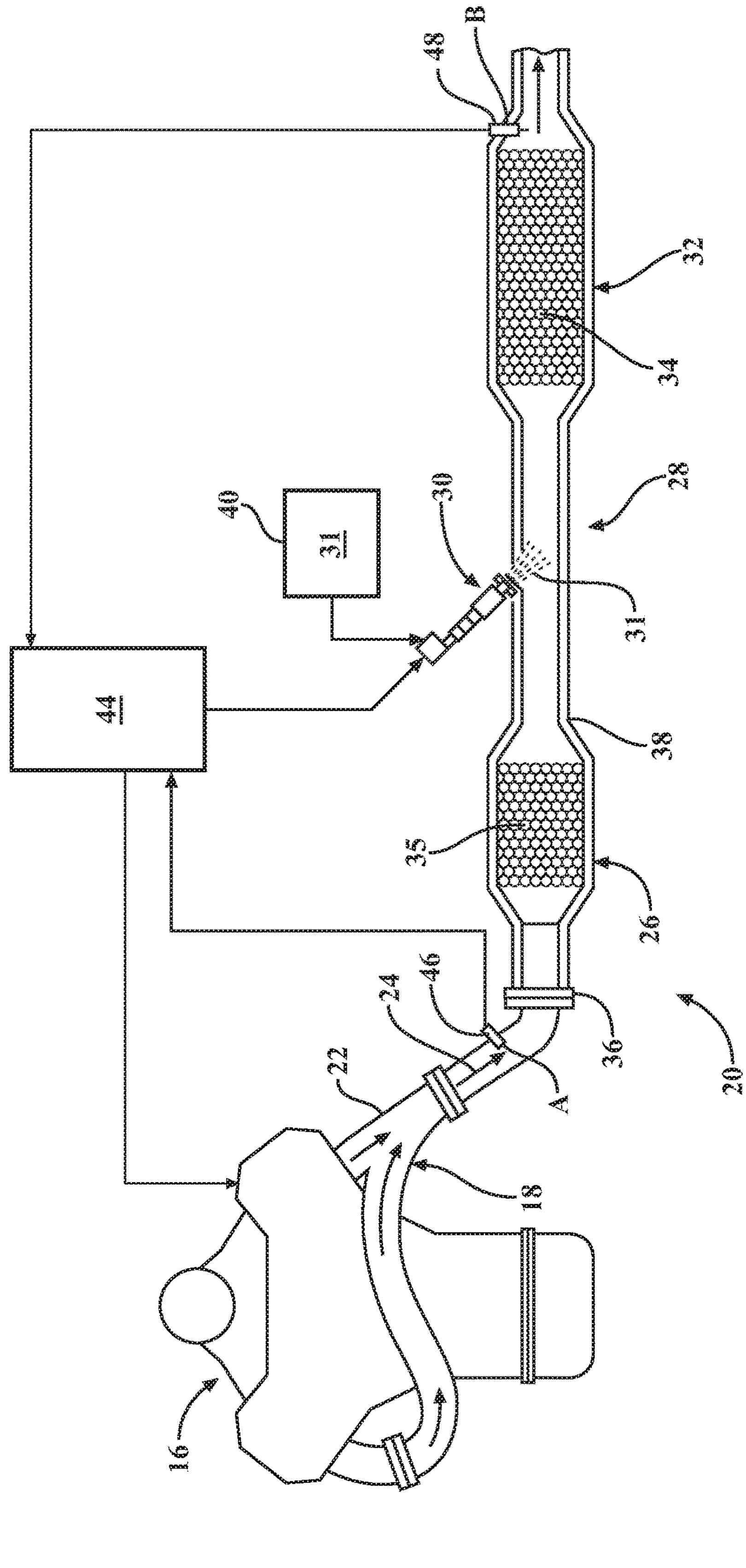


FIG. 2

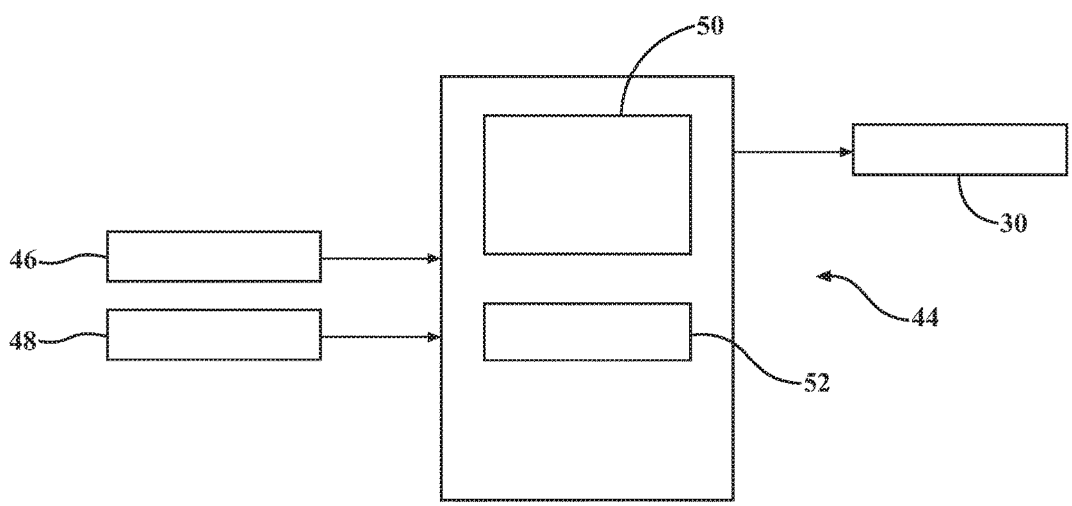


FIG. 3

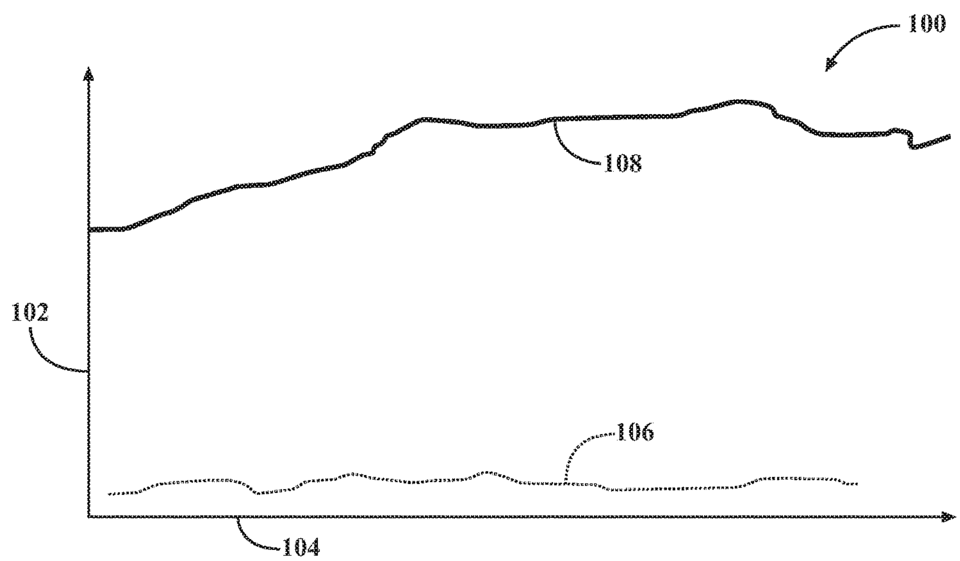


FIG. 4

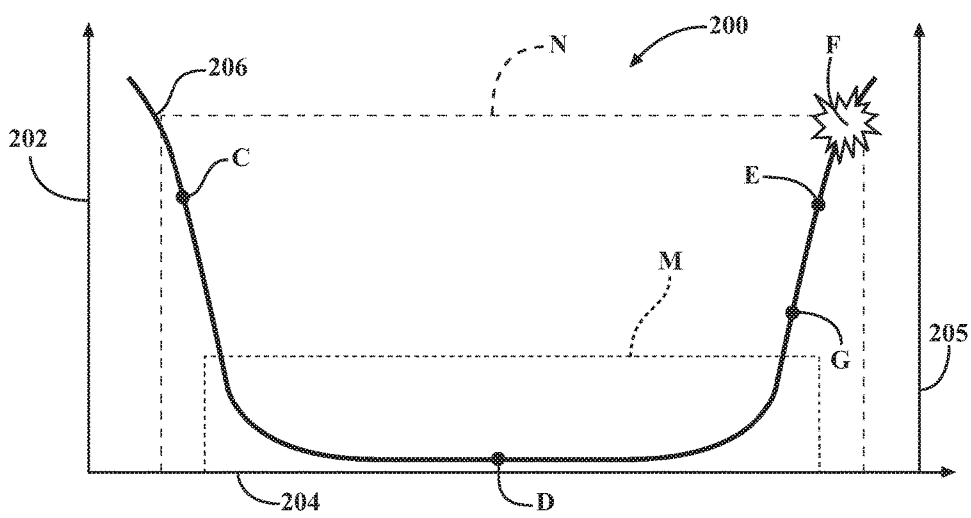


FIG. 5

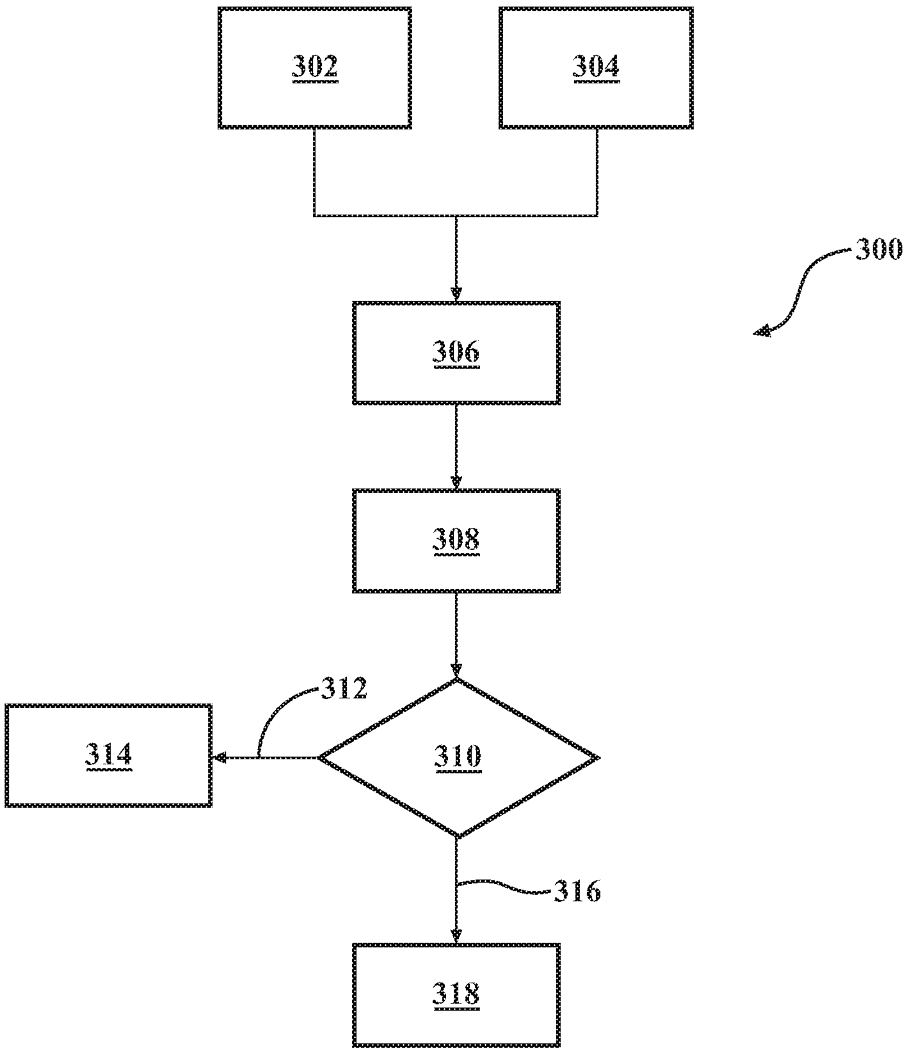


FIG. 6

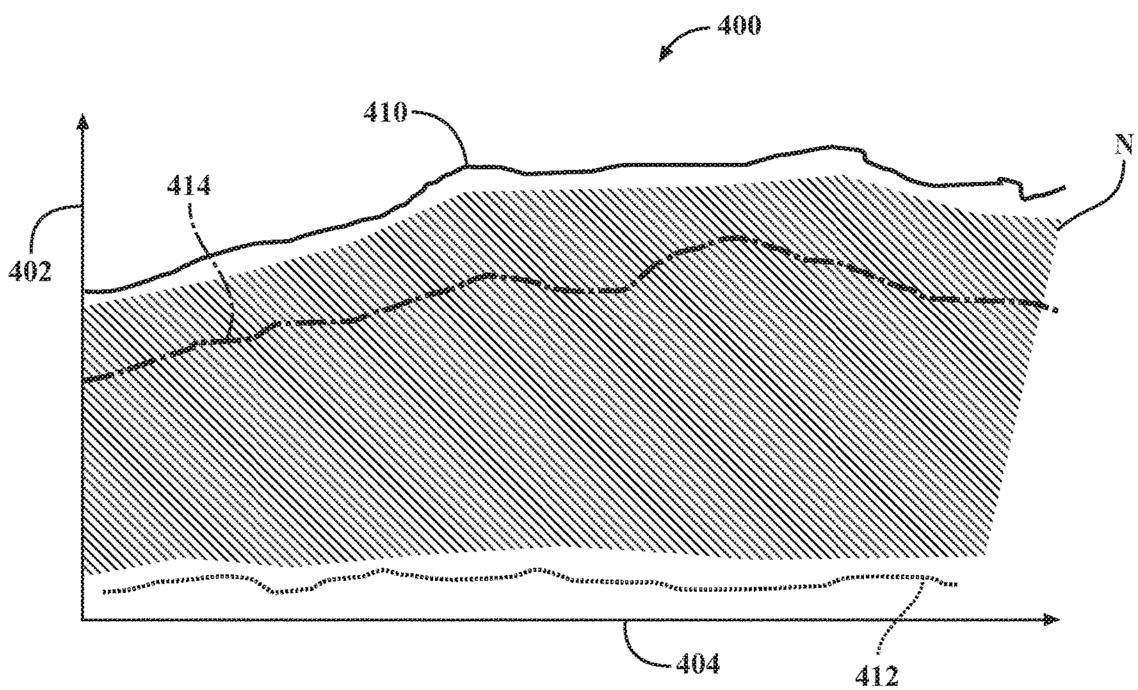
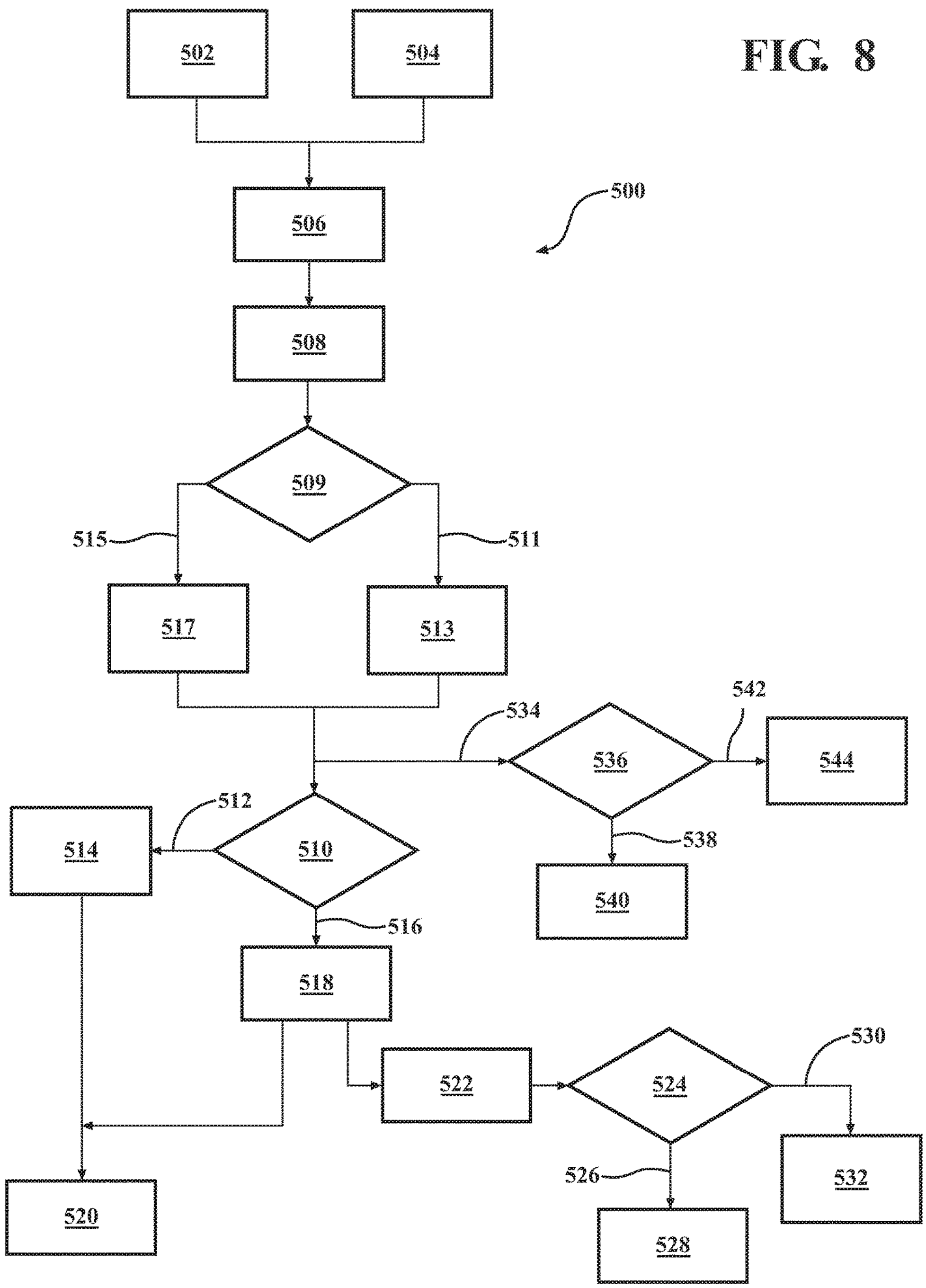


FIG. 7

FIG. 8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CONTROL RESET AND DIAGNOSTIC TO MAINTAIN TAILPIPE COMPLIANCE

FIELD

[0001] The subject disclosure relates to selective catalytic reduction in motor vehicles and, more particularly, to a method and system for controlling a selective catalytic reduction system.

INTRODUCTION

[0002] A selective catalytic reduction (SCR) system relies on a catalyst having a washcoat and a gaseous reductant to convert nitrogen oxide compounds (NO_x) into nitrogen and water. During operation, a reductant, such as ammonia or urea, is injected into a housing of the SCR system in an amount sufficient to promote a chemical reaction that maintains desirable performance characteristics.

[0003] Maintaining the desirable reductant injection ensures that emissions exiting a tail pipe stay within selected ranges. Too little reductant results in NO_x emissions remaining unconverted, while too much reductant wastes reductant and may also result in the extra reductant itself converting to NO_x and/or slipping into the atmosphere. When too much reductant is injected through the SCR device, an excess of ammonia may exist, a condition that is referred to as ammonia slip because ammonia slips through without reacting with existing NO_x. As will be explained in greater detail below, if the amount of ammonia slip becomes high enough or the perceived extra ammonia within the SCR system is perceived by the control system as being more than adequate, the control loop may become stuck and will cut off all reductant injection.

[0004] Accordingly, it is desirable to provide a system and method to control the SCR system to ensure that proper levels of reductant are injected to abate emissions as desired.

SUMMARY

[0005] The present disclosure provides an SCR control system that resets an upstream NO_x sensor signal to a predetermined calibrated model of the upstream NO_x sensor signal when the downstream NO_x sensor signal exceeds the upstream NO_x sensor signal (or integrated upstream NO_x sensor signal) by a certain threshold, to avoid a stuck sensor resulting in the halting of reductant injection.

[0006] In one form, which may be combined with or separate from the other forms disclosed herein, a method of controlling a selective catalyst reduction (SCR) reductant delivery system is provided. The method includes determining an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location upstream of a reductant injector to define a determined upstream NO_x amount, and determining an amount of NO_x present in the tailpipe at a second location downstream of the reductant injector to define a determined downstream NO_x amount. The method further includes subtracting the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value, and determining a cumulative difference based on the subtracted NO_x value. In addition, the method includes determining whether the cumulative difference exceeds a control threshold. The method includes setting a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold and setting the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

[0007] In another form, which may be combined with or separate from the other forms disclosed herein, a selective catalytic reduction reductant injection control module is provided that includes a processor and a non-volatile memory including a set of instructions which are configured to cause the processor to perform the following: determine an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location upstream of a reductant injector to define a determined upstream NO_x amount; determine an amount of NO_x present in the tailpipe at a second location downstream of the reductant injector to define a determined downstream NO_x amount; subtract the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value; determine a cumulative difference based on the subtracted NO_x value; determine whether the cumulative difference exceeds a control threshold; set a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold; and set the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

[0008] In yet another form, which may be combined with or separate from the other forms disclosed herein, a vehicle system is provided that includes a tailpipe and a selective catalytic reduction (SCR) system including a reductant injector and a housing, where the reductant injector is configured to inject a reductant into the housing, the housing being in fluid communication with the tailpipe. An upstream NO_x sensor configured to measure nitrogen oxide compounds (NO_x) in an exhaust flow stream is disposed in fluid communication with the tailpipe at a location upstream of the SCR system. A downstream NO_x sensor configured to measure NO_x in the exhaust flow stream is disposed in fluid communication with the tailpipe at a location at least partially downstream of the SCR system. A reductant injection control module includes a processor and a non-volatile memory including a set of instructions configured to cause the processor to: determine an amount of NO_x present in the tailpipe based on an upstream signal from the upstream NO_x sensor to define a determined upstream NO_x amount; determine an amount of NO_x present in the tailpipe based on a downstream signal from the downstream NO_x sensor to define a determined downstream NO_x amount; subtract the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value; determine a cumulative difference based on the subtracted NO_x value; determine whether the cumulative difference exceeds a control threshold; set a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold; and set the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

[0009] Further additional features may be provided, including but not limited to the following: the method or control/vehicle system being configured to determine whether to inject a reductant based on the selected upstream NO_x value and the determined downstream NO_x amount; the method or control/vehicle system being configured to inject the reductant according to a predetermined model based on the selected upstream NO_x value and the determined downstream NO_x amount; the method or control/vehicle system being configured to determine the determined upstream NO_x amount as a mass of NO_x based on an upstream exhaust fluid flow rate at the first location; the method or control/vehicle system being configured to determine the determined downstream NO_x amount as a mass of NO_x based on a downstream exhaust fluid flow rate at the second location; the method or control/vehicle system being configured to determine the cumulative difference by integrating the subtracted NO_x value with previous subtracted NO_x values obtained earlier in a key cycle; the method or control/vehicle system being configured to determine whether the cumulative difference exceeds a diagnostic threshold; the method or control/vehicle system being configured to activate a diagnostic signal if the cumulative difference exceeds the diagnostic threshold; the method or control/vehicle system being configured to determine the control threshold and the diagnostic threshold based on a maximum ammonia storage capacity of the SCR system; the method or control/vehicle system being configured to determine a maximum storage capacity multiplier based on the maximum ammonia storage capacity of the SCR system; the method or control/vehicle system being configured to determine the control threshold by multiplying the maximum storage capacity multiplier by a control constant; the method or control/vehicle system being configured to determine the diagnostic threshold by multiplying the maximum storage capacity multiplier by a diagnostic constant; wherein the diagnostic constant is greater than the control constant; wherein the diagnostic threshold is greater than the control threshold; the method or control/vehicle system being configured to increment a counting device to define a count each time the selected upstream NO_x value is set as the predetermined model upstream NO_x amount; and the method or control/vehicle system being configured to diagnose a sensor error if the count exceeds a predetermined count threshold.

[0010] Further aspects, advantages and areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0012] FIG. **1** is a schematic plan view of a vehicle including an SCR system, in accordance with the principles of the present disclosure;

[0013] FIG. **2** is a schematic plan view of a tailpipe assembly of the vehicle of FIG. **1**, including the SCR system, according to the principles of the present disclosure;

[0014] FIG. **3** is a block diagram illustrating a controller configured to adjust reductant injection by the SCR system of FIGS. **1-2**, in accordance with the principles of the present disclosure;

[0015] FIG. **4** is a graph illustrating a condition wherein a NO_x sensor located downstream of the SCR system of FIGS. **1-2** reads a higher amount of NO_x than a NO_x sensor located upstream of the SCR system;

[0016] FIG. **5** is a graph illustrating an example reductant injection profile of the SCR system of FIGS. **1-2** as a function of the downstream NO_x sensor reading and an amount of perceived ammonia in the SCR system, according to the principles of the present disclosure;

[0017] FIG. **6** is a block diagram illustrating a method of controlling an SCR reductant delivery system, in accordance with the principles of the present disclosure;

[0018] FIG. **7** is a graph illustrating an upstream NO_x sensor signal, a downstream NO_x sensor signal, and a predetermined model of an upstream NO_x sensor signal, all as functions of time, in accordance with the principles of the present disclosure; and

[0019] FIG. **8** is a block diagram illustrating another method of controlling an SCR reductant delivery system, according to the principles of the present disclosure.

DETAILED DESCRIPTION

[0020] The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features. As used herein, the term module refers to processing circuitry that may include an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

[0021] Referring now to FIG. **1**, a vehicle is schematically illustrated and generally designated at **10**. The vehicle **10** is shown in the form of a pick-up truck, however, it should be understood that the vehicle **10** may take on any other variety of forms. The vehicle **10** includes a frame **12** that supports a body **14** and an internal combustion engine **16**. The internal combustion engine **16** includes an exhaust system **18** and an exhaust gas after-treatment system **20** for the reduction of regulated exhaust gas constituents of the internal combustion (IC) engine **16**. In the illustrated example, the engine **16** is a diesel engine running on diesel fuel, but in the alternative, the engine **16** could be another type of engine, such as a gasoline engine.

[0022] Referring now to FIG. **2** and with continued reference to FIG. **1**, the exhaust gas after-treatment system **20** generally includes one or more exhaust gas conduits defined by a tailpipe **22**, that channels exhaust gases **24** to one or more exhaust treatment devices. The exhaust gas treatment devices may include, but are not limited to, an oxidation catalyst (OC) device **26** and a selective catalytic reduction (SCR) system **28**. By way of example, the SCR system **28** may include one or more reductant injectors **30** configured to inject a reductant **31**, such as a diesel exhaust fluid (DEF) containing urea or ammonia, into the conduit defined by the tailpipe **22**. A housing **32** having a filter portion **34**, which may take the form of a particulate filter (PF), such as a diesel particulate filter, may also be included as shown. As can be appreciated, the exhaust gas after-treatment system **20** may include various combinations of the exhaust treatment elements shown and/or other exhaust treatment devices that are not shown. Thus, exemplary embodiments should not be considered to be limited to the present example.

[0023] The OC **26** can be one of various flow-through, oxidation catalyst devices known in the art, or OC **26** could be a wall-flow (particular filter), by way of example. The OC **26** may include a flow-through metal or ceramic monolith substrate **35**. The substrate **35** may be packaged in a stainless steel shell or canister (also not separately labeled) having an inlet **36** and an outlet **38** in fluid communication with the exhaust gas conduit or tailpipe **22**. The substrate **35** may include an oxidation catalyst compound disposed thereon. The oxidation catalyst compound may be applied as a washcoat and may contain platinum group metals such as platinum (Pt), palladium (Pd), rhodium (Rh), or other suitable oxidizing catalysts, or a combination thereof. The OC **26** is useful in treating unburned gaseous and non-volatile HC and CO, which are oxidized to form carbon dioxide and water.

[0024] The SCR system **28** may be disposed downstream of the OC **26**, with housing **32** and filter portion **34** being disposed downstream of the injector(s) **30**. The filter portion **34** may include a catalyst-containing washcoat disposed thereon. The catalyst-containing washcoat may reduce NO_x in the exhaust stream by utilizing the reductant **31** from the injector(s) **30** to convert the NO_x into N_2 and H_2O, as understood by those ordinarily skilled in the art. The reductant **31** injected by the injector(s) **30** may include, but is not limited to, ammonia (NH_3) and/or urea ($CO(NH_2)_2$). The catalyst-containing washcoat may contain, but is not limited to, a zeolite and one or more base metal components such as iron (Fe), cobalt (Co), copper (Cu), silver (Ag) or vanadium (V), which can operate efficiently to convert NO_x constituents in the exhaust gas **24** into acceptable byproducts (e.g., diatomic nitrogen (N_2) and water (H_2O)) in the presence of NH_3. The reductant **31** utilized by the SCR system **28** may be in the form of a solid, a gas, a liquid, or an aqueous urea solution and may be mixed with air to aid in dispersion of the injected spray.

[0025] The filter portion **34** of the housing **32** may also be configured to filter the exhaust gases **24** of carbon and other particulate matter. The filter portion **34** may be constructed using, for example, a ceramic or metallic (e.g., silica carbonite) wall flow monolith exhaust gas filter substrate that is packaged in a rigid, heat resistant shell or canister, having an inlet and an outlet in fluid communication with exhaust gas conduit **22**. The ceramic wall flow monolith filter substrate is merely exemplary in nature, and the filter portion **34** may include other filter devices such as wound or packed fiber filters, open cell foams, sintered metal fibers, etc. The filter substrate may include a ceramic filter element (e.g., a wall-flow element) configured to trap particulate matter included in the exhaust gas **24**. The exhaust gas aftertreatment system **20** may perform a regeneration process that regenerates the filter portion **34** by burning off the particulate matter trapped in the filter substrate, if desired.

[0026] The SCR system **28** introduces the reductant **31** to the exhaust gas **24**. A reductant supply source **40** holding an amount of reductant **31** is supplied to the injector(s) **30**, as controlled by a reductant injection control module **44**. The reductant supply source **40** is in fluid communication with the injector(s) **30**. As stated above, the reductant **31** may include, but is not limited to, ammonia (NH_3) and urea. Accordingly, the injector(s) **30** may inject a selectable amount of reductant **31** into the exhaust gas conduit **22** such that the reductant **31** is introduced to the exhaust gas **24** at a location upstream of the housing **32**.

[0027] An upstream NO_x sensor **46** is configured to measure nitrogen oxide compounds (NO_x) in the exhaust flow stream **24** within the exhaust conduit defined by the tailpipe **22** at a location A that is upstream from the SCR system **28**. The location A is one example of the possible upstream locations for the upstream NO_x sensor **46**, but the upstream NO_x sensor **46** could alternatively be located at any other location upstream of the injector(s) **30**, such as downstream of the OC **26**. The upstream NO_x sensor **46** is disposed in fluid communication with the exhaust conduit defined by the tailpipe **22**.

[0028] A downstream NO_x sensor **48** is configured to measure nitrogen oxide compounds (NO_x) in the exhaust flow stream **24** within the exhaust conduit defined by the tailpipe **22** at a location B that is downstream from the SCR **28**. The downstream NO_x sensor **48** may also have sensitivities to NH_3, resulting in similar responses by the sensor electrode to NH_3 as to NO_x. The location B, which is located downstream of the injector(s) **30** and the housing **32** having the filter **34**, is one example of the possible downstream locations for the downstream NO_x sensor **48**, but the downstream NO_x sensor **48** could alternatively be located at another location downstream of the injector(s) **30**, if desired. For example, the NO_x sensor **48** could be located downstream of the injector(s) **30**, but upstream of the housing **32** and filter **34**. The downstream NO_x sensor **48** is disposed in fluid communication with the exhaust conduit defined by the tailpipe **22**.

[0029] Each of the NO_x sensors **46**, **48** is configured to measure the amount of NO_x, typically in PPM, in the flow stream **24** at the locations A, B, respectively. The NO_x sensors **46**, **48** send signals to the control module **44** for further processing.

[0030] With reference to FIG. **3**, and continued reference to FIG. **2**, the reductant injection control module **44** includes a processor **50** functionally connected to a non-volatile memory **52** containing program instructions. The reductant injection control module **44** may determine and adjust an amount of reductant **31**, such as urea, to be injected into exhaust gases **24** based on feedback from the upstream and downstream NO_x sensors **46**, **48**. More particularly, when the downstream NO_x sensor **48** senses NO_x at location B, the control system **44** typically determines that more of the reductant **31** should be injected to convert the NO_x in the flow stream **24** to nitrogen and water.

[0031] Typically, the downstream NO_x sensor **48** would read a lower level of NO_x than the upstream NO_x sensor **46**, because the NO_x that existed upstream at location A would have been reduced by the SCR system **28**. Most preferably, the NO_x at the downstream NO_x sensor **48** (at location B) is at or near zero.

[0032] Referring now to FIG. **4**, a graph **100** illustrates a condition wherein the downstream NO_x sensor **48** reads a higher level of NO_x than the upstream NO_x sensor **46**. The NO_x sensor reading level is illustrated on the vertical axis at **102**, while time is illustrated on the horizontal axis at **104**. The NO_x signal sent by the upstream NO_x sensor **46** is illustrated at trace **106**, and the NO_x signal sent by the downstream NO_x sensor **48** is illustrated at trace **108**. In this case, the NO_x signal is higher at the downstream NO_x sensor **48** than at the upstream NO_x sensor **46**.

[0033] FIG. **5** helps explain why the NO_x signal might be higher at the downstream NO_x sensor **48** than at the upstream NO_x sensor **46**. FIG. **5** is a graph **200** illustrating the downstream NOx sensor **48** reading on the left vertical axis at **202**, with the amount of ammonia illustrated along the horizontal axis at **204**. The trace **206** represents the amount of reductant **31** being injected by the injector **30**, which is controlled by the controller **44**, and correlates to a right vertical axis **205** corresponding to an amount of reductant injected. At the left side of the graph **200** at location C, with high levels of NO_x at the location B of the downstream NO_x sensor **48** and with low levels of ammonia, a high amount of injection incurs, as shown by trace **206**, as would be expected. As more reductant is injected, the downstream NO_x levels diminish, such as at point D. A calibrated system model is programmed into the controller **44** to keep the NO_x levels low at the downstream location B, and the sensor model operates within the range represented by the model box M.

[0034] If ammonia levels become too high, and ammonia slip is occurring, the ammonia can actually react and turn into NO_x. In addition or in the alternative, the downstream NO_x sensor **48** can read all or some of the excess ammonia as NO_x and the excess NH_3 may slip out of the tailpipe **22** unless it reacts with a downstream component. Thus, at the right side of the graph **200**, such at location E, a high amount of ammonia exists in the system and the downstream NO_x sensor signal is high. Accordingly, the controller **44** interprets that there is enough ammonia to reduce all of the NO_x. The maximum capacity of the SCR housing **20** is represented by box N. At point F, the downstream NO_x sensor **48** signal is so high that the amount of ammonia is interpreted by the controller **44** to be as much as the physical constraints of the SCR system **28** can hold. Accordingly, the injection of reductant **31** through the injector **30** is completely stopped until the ammonia can be "used up."

[0035] However, the problem is that the downstream NO_x sensor **48** is still high at point F, and therefore, the control system **44** is unable to determine whether NO_x or ammonia is high (or both are). This illustration of high ammonia slip at point F may occur, for example, if one of the sensors **46**, **48** is faulty or "stuck," or if the upstream NO_x offset has been set too low.

[0036] Referring now to FIG. **6**, a method **300** is illustrated for controlling an SCR reductant delivery system, such as the control module **44** and the SCR system **28**. The method **300** may be implemented as an instruction by the processor **50** and memory **52** of the controller or control module **44**. The method **300** includes a step **302** of determining an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location (such as location A) upstream of a reductant injector to define a determined upstream NO_x amount and a step **304** of determining an amount of NO_x present in the tailpipe at a second location (such as location B) downstream of the reductant injector to define a determined downstream NO_x amount. The steps **302** and **304** may be performed simultaneously, or one after the other, by way of example. In some implementations, the amounts of NO_x are based one signals sent from the upstream and downstream NO_x sensors **46**, **48** that may be continuous or periodic, and the control system **44** may be configured to monitor the sensor signals and to repeat the steps of the method **300**.

[0037] The NO_x signals from each of the sensors **46**, **48** may be further processed so that the determined downstream NO_x amount and the determined upstream NO_x amount may be determined as masses of NO_x. The masses of NO_x may be determined based on NO_x amounts determined in parts-per-million ppm by the sensors **46**, **48** and by taking into account the flow rate of the exhaust stream at the points A, B of each of the sensors **46**, **48**, respectively.

[0038] The method **300** then includes a step **306** of subtracting the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value. The subtracted NO_x value will only be positive if the downstream NO_x amount is greater than the upstream NO_x amount.

[0039] The method **300** has a step **308** of determining a cumulative difference based on the subtracted NO_x value. If the subtracted NO_x value is the first subtracted NO_x value obtained, then the cumulative difference will be the subtracted NO_x value, or in some examples, the cumulative difference may be defined to be the subtracted NO_x value. In other examples, however, the cumulative difference may represent a summation or integral of subtracted NO_x values that are determined by the control module **44**. Thus, if the system is being well controlled (e.g., in the M region in graph **200** of FIG. **5**), some subtracted NO_x values will be positive and some will be negative, cancelling each other out, and the cumulative difference will remain at or near zero. However, if the ammonia slip is creeping up as shown on the right side of the graph **200** in FIG. **5**, the cumulative difference will rise each time that a subtracted NO_x value is determined.

[0040] The method **300** proceeds from step **308** to a step **310** of determining whether the cumulative difference exceeds a control threshold. For example, the control module **44** could be programmed with a predetermined control threshold beyond which it would be desirable to take action to correct the ammonia slip. The control threshold could be, for example, at point E on the graph **200** in FIG. **5**, or even sooner along the ammonia slip continuum, such as at point G. If, in step **310**, it is determined that the cumulative difference does not exceed the control threshold, the method **300** proceeds along path **312** to step **314**. In step **314**, a selected upstream NO_x value is set as the determined upstream NO_x amount. Thus, the upstream NO_x amount that is determined from the signal of the upstream NO_x sensor **46** is used by the controller **44** to control the injection of the reductant **31**. The system is well controlled when the subtracted NO_x value or the cumulative difference does not exceed the control threshold, as explained above.

[0041] If, however, the cumulative difference does exceed the control threshold, the method **300** proceeds from step **310** along path **316** to step **318**. Thus, the downstream NO_x sensor **48** signal is sending a high enough signal over the signal of the upstream NO_x sensor **46** that the cumulative difference goes beyond the preset control threshold. In such a case, it is desirable to correct the system to bring the NO_x or ammonia slip under control. In this case, it is believed that the upstream NO_x sensor **46** signal may be erroneous, and therefore, reductant **31** injection may soon be halted or already be halted (depending on where the control threshold is set). Therefore, in the step **318**, the method **300** includes setting the selected upstream NO_x value as a predetermined model upstream NO_x amount. More particularly, a predetermined model of an expected signal from the upstream NO_x sensor **46** may be programmed into the controller **44**, and the controller **44** may revert to using this model of the upstream NO_x amount in order to bring the upstream and downstream NO_x sensor signals closer together and the system back under control.

[0042] For example, referring to FIG. **7**, a graph **400** illustrates NO_x levels on a vertical axis at **402**, with time on a horizontal axis at **404**. A NO_x signal from the downstream NO_x sensor **48** is illustrated at trace **410**, and a NO_x signal from the upstream NO_x sensor **46** is illustrated at trace **412**.

The physical constraints of the SCR reductant delivery system **28** are represented by area N. With the upstream and downstream NO_x signals **412**, **410** being outside of the physical constraints N of the SCR system **28**, the controller **44** may be in a stuck mode wherein reductant **31** that should be delivered is not delivered via the injector **30** to reduce NO_x because the control module **44** sees that system as already being saturated with ammonia. Accordingly, as in step **318** of FIG. **6**, the upstream NO_x signal **412** is replaced by a predetermined model NO_x signal **414**. The signal **414** is a calibrated upstream NO_x signal for a model of a well-controlled system.

[0043] The controller **44** then uses the model signal **414** instead of the true upstream NO_x sensor signal **412** for purposes of controlling the injection of reductant **31**, and the method **300** may then restart. The cumulative difference will continue to be determined at step **308**, and in some circumstances, the control system **44** may be able to regain control over the ammonia slip and bring the NO_x levels back into the desired sensor model region M shown in FIG. **5**.

[0044] Referring now to FIG. **8**, another variation of a method for controlling an SCR reductant delivery system, such as system **28**, is illustrated and generally designated at **500**. The method **500** includes additional details over the method **300** described above, and any of the details described herein with respect to the method **500** may be equally applied to the method **300**, if desired. Like the method **300**, the method **500** may be implemented as an instruction set by the processor **50** and memory **52** of the controller or control system **44**.

[0045] The method **500** includes a step **502** of determining an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location upstream of a reductant injector to define a determined upstream NO_x amount and a step **504** of determining an amount of NO_x present in the tailpipe at a second location downstream of the reductant injector to define a determined downstream NO_x amount. The steps **502** and **504** may be performed simultaneously, or one after the other, by way of example. In some implementations, the amounts of NO_x are based on signals sent from the upstream and downstream NO_x sensors **46**, **48** that may be continuous or periodic, and the control system **44** may be configured to monitor the sensor signals.

[0046] The NO_x signals from each of the sensors **46**, **48** may be further processed so that the determined downstream NO_x amount and the determined upstream NO_x amount may be determined as masses of NO_x. The masses of NO_x may be determined based on NO_x amounts determined in parts-per-million ppm by the sensors **46**, **48** and by taking into account the flow rate of the exhaust stream at the points A, B of each of the sensors **46**, **48**, respectively.

[0047] The method **500** then includes a step **506** of subtracting the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value. The subtracted NO_x value will only be positive if the downstream NO_x amount is greater than the upstream NO_x amount.

[0048] The method **500** has a step **508** of determining a cumulative difference based on the subtracted NO_x value. If the subtracted NO_x value is the first subtracted NO_x value obtained, then the cumulative difference will be the subtracted NO_x value, or in some examples, the cumulative difference may be defined to be the subtracted NO_x value. In other examples, however, the cumulative difference may represent a summation or integral of subtracted NO_x values that are determined by the controller **44**. Thus, the cumulative difference may be determined by integrating the subtracted NO_x value with previous subtracted NO_x values obtained earlier in a key cycle.

[0049] If the system is being well controlled, some subtracted NO_x values will be positive and some will be negative, cancelling each other out, and the cumulative difference (the integral of the subtracted NO_x values) will remain at or near zero. However, if the ammonia slip is creeping up at shown on the right side of the graph **200** in FIG. **5**, the cumulative difference will rise each time that a subtracted NO_x value is determined.

[0050] The method **500** then may proceed to an optional step **509** of determining whether the cumulative difference is above zero, e.g., not a negative number. If the cumulative difference is above zero, which indicates that the downstream NO_x amount is greater than the upstream NO_x amount, the method **500** proceeds along route **511** to step **513**. In step **513**, the cumulative difference is used as previously calculated or determined, and the cumulative difference value is used in the next step **510**.

[0051] If, however, in step **509** it is determined that the cumulative difference is negative or below zero, which indicates that the downstream NO_x amount is less than the upstream NO_x amount, the method **500** proceeds along route **515** to step **517**. In step **517**, the cumulative difference is assigned a value of zero, and zero is used for the cumulative difference value in the next step **510**.

[0052] Step **510** may be similar to the step **310** described above with respect to FIG. **6**. In step **510**, the method **500** includes determining whether the cumulative difference value (as determined in either step **513** or **517**) exceeds a control threshold. For example, the controller **44** could have some predetermined control threshold beyond which it would be desirable to take action to correct the ammonia slip. The control threshold could be, for example, at point E on the graph **200** in FIG. **5**, or even sooner along the ammonia slip continuum, such as at point G.

[0053] If, in step **510**, it is determined that the cumulative difference does not exceed the control threshold, the method **500** proceeds along path **512** to step **514**. In step **514**, a selected upstream NO_x value is set as the determined upstream NO_x amount. Thus, the upstream NO_x amount that is determined based on the signal of the upstream NO_x sensor **46** is used by the controller **44** to control the injection of the reductant **31**. The system is well controlled when the subtracted NO_x value or the cumulative difference does not exceed the control threshold, as explained above.

[0054] If, however, the cumulative difference does exceed the control threshold, the method **500** proceeds from step **510** along path **516** to step **518**. Thus, the downstream NO_x sensor **48** signal is showing a high enough value over the upstream NO_x sensor **46** (with flow rate taken into consideration) that the cumulative difference goes beyond the preset control threshold. In such a case, it is desirable to correct the system to bring the NO_x or ammonia slip under control. The upstream NO_x sensor **46** signal may be erroneous, and therefore, reductant **31** injection may soon be halted or already be halted (depending on where the control threshold is set).

[0055] Therefore, in the step **518**, the method **500** includes setting the selected upstream NO_x value as a predetermined model upstream NO_x amount. More particularly, a predetermined model of an expected signal from the upstream NO_x sensor **46** may be programmed into the controller **44**, and the controller **44** may revert to using this model of the upstream NO_x amount in order to bring the upstream and downstream NO_x sensor signals closer together and the system back under control. Thus, the model upstream signal **414** shown in FIG. **7** may be used, as explained above. The upstream NO_x signal **412** is replaced by a predetermined model NO_x signal **414**. The signal **414** is a calibrated upstream NO_x signal for a model of a well-controlled system.

[0056] The method **500** proceeds from either of the steps **514**, **518** that was selected by the step **510** to a step **520**. In step **520**, the method **500** includes injecting reductant **31**, or determining whether to inject reductant **31**, based on the downstream NO_x amount and on the selected upstream NO_x value, which could be the upstream NO_x amount as applied in step **514** or the predetermined model upstream NO_x amount as applied in step **518**.

[0057] As explained above, if the method **500** or controller **44** uses the model signal **414** instead of the true upstream NO_x sensor signal **412** for purposes of controlling the injection of reductant **31**, the system may be brought back under control into the model region M, as desired. The method **500** may then restart and the cumulative difference will continue to be determined at step **508**, and in some circumstances, the control system **44** may be able to regain control over the ammonia slip and bring the NO_x levels back into the desired sensor model region M shown in FIG. **5**.

[0058] In addition to determining whether to reset the control to the model control signal as determined by **510**, after determining the cumulative difference in step **508**, the method **500** may include further diagnostic steps, in some variations of the method **500**. For example, each time that the method **500** determines in step **510** to follow path **516** to select the predetermined model as the upstream NO_x value in step **518**, the method **500** may also include a step **522** of incrementing a counting device. Thus, in step **522**, the method **500** or controller **44** increments a counting device to define a count each time the selected upstream NO_x value is set as the predetermined model upstream NO_x amount.

[0059] The method **500** may then apply the count in a step **524** to determine whether the count exceeds a predetermined count threshold. If the count does not exceed the predetermined count threshold (e.g., the system has not been reset at least the number of times in the count threshold), the method **500** proceeds along path **526** to step **528**, where the method **500** determines that the count threshold is not met.

[0060] If, however, in step **524** it is determined that the count does exceed the predetermined count threshold, the method **500** proceeds along a path **530** to step **532**. In step **532**, where the count has exceeded the predetermined count threshold, the method **500** or control system **44** diagnoses a sensor error. Thus, the control system **44** or method **500** concludes that perhaps one of the NO_x sensors **46**, **48** may have an error since the system is continuously having to reset the upstream NO_x amount to the predetermined model.

[0061] Furthermore, in addition to determining whether to reset the control to the model control signal as determined by **510**, after determining the cumulative difference in step **508**, the method **500** may include another diagnostic logic route **534**. The method **500** may proceed from step **513** or **517** (or step **508**), along path **534** to diagnostic step **536**.

[0062] In step **536**, the method **500** includes determining whether the cumulative difference value (as determined in either step **513** or **517**) exceeds a diagnostic threshold (which may have a different value than the control threshold used in step **510**). For example, the controller **44** could have some predetermined diagnostic threshold beyond which it would be desirable to activate a diagnostic alert. The diagnostic threshold could be, for example, at point F on the graph **200** in FIG. **5**, or sooner along the ammonia slip continuum, such as at point E, if desired.

[0063] If, in step **536**, it is determined that the cumulative difference does not exceed the diagnostic threshold, the method **500** proceeds along path **538** to step **540**. In step **540**, the method **500** determines not to activate any diagnostic signal because the diagnostic threshold is not met. The method **500** may then restart as desired to continue to monitor the NO_x sensor signals and to update the cumulative difference.

[0064] If, however, the cumulative difference does exceed the diagnostic threshold, the method **500** proceeds from step **536** along path **542** to step **544**. Thus, the downstream NO_x sensor **48** signal is showing a high enough value over the upstream NO_x sensor **46** (with flow rate taken into consideration) that the cumulative difference goes beyond the preset diagnostic threshold. In such a case, it is desirable to set a diagnostic alert or otherwise activate a diagnostic signal. The upstream NO_x sensor **46** signal may be erroneous, and therefore, reductant **31** injection may soon be halted or already be halted (depending on where the diagnostic threshold is set).

[0065] Therefore, in the step **544**, the method **500** includes activating a diagnostic signal. The diagnostic signal could include, for example, turning on a check-engine light.

[0066] Referring to FIG. **5**, both the control threshold and the diagnostic threshold may be determined based on a maximum ammonia storage capacity threshold M of the of the selective catalytic reduction system **28**. A maximum storage capacity multiplier may be determined based on the maximum ammonia storage capacity N of the SCR system **28**, and that multiplier may be used to determine the control threshold and the diagnostic threshold. In one example, the maximum storage capacity multiplier may be multiplied by a control constant to determine the control threshold, and the maximum storage capacity multiplier may be multiplied by a diagnostic constant to determine the diagnostic threshold. In the alternative, the control threshold and the diagnostic threshold may be determined separate of the maximum storage capacity, in any other desirable manner. The diagnostic constant may be greater than the control constant, so that the system may try to correct itself using the upstream NO_x reset prior to activating the diagnostic alert, which would then occur when the reset does not achieve bringing the system under control.

[0067] The terms controller, control module, module, control, control unit, processor and similar terms refer to any one or various combinations of Application Specific Integrated Circuit(s) (ASIC), electronic circuit(s), central processing unit(s), e.g., microprocessor(s) and associated non-transitory memory component in the form of memory and storage devices (read only, programmable read only, random access, hard drive, etc.). The non-transitory memory component may be capable of storing machine readable instructions in the form of one or more software or firmware programs or routines, combinational logic circuit(s), input/output circuit(s) and devices, signal conditioning and buffer circuitry and other components that can be accessed by one or more processors to provide a described functionality.

[0068] Input/output circuit(s) and devices include analog/digital converters and related devices that monitor inputs from sensors, with such inputs monitored at a preset sampling frequency or in response to a triggering event. Software, firmware, programs, instructions, control routines, code, algorithms and similar terms can include any controller-executable instruction sets including calibrations and look-up tables. Each controller executes control routine(s) to provide desired functions, including monitoring inputs from sensing devices and other networked controllers and executing control and diagnostic instructions to control operation of actuators. Routines may be executed at regular intervals, for example each 100 microseconds during ongoing operation. Alternatively, routines may be executed in response to occurrence of a triggering event.

[0069] Communication between controllers, and communication between controllers, actuators and/or sensors may be accomplished using a direct wired link, a networked communication bus link, a wireless link or any another suitable communication link. Communication includes exchanging data signals in any suitable form, including, for example, electrical signals via a conductive medium, electromagnetic signals via air, optical signals via optical waveguides, and the like.

[0070] Data signals may include signals representing inputs from sensors, signals representing actuator commands, and communication signals between controllers. The term 'model' refers to a processor-based or processor-executable code and associated calibration that simulates a physical existence of a device or a physical process. As used herein, the terms 'dynamic' and 'dynamically' describe steps or processes that are executed in real-time and are characterized by monitoring or otherwise determining states of parameters and regularly or periodically updating the states of the parameters during execution of a routine or between iterations of execution of the routine.

[0071] The control module **44** of FIG. **2** may be programmed to execute the steps of the methods **300**, **500** as defined with reference to FIGS. **3** and **5**.

[0072] The terminology used herein is for the purpose of describing particular examples only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0073] While the above disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from its scope. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular examples disclosed, but will include all examples falling within the scope the appended claims.

What is claimed is:

1. A method of controlling a selective catalytic reduction reductant delivery system, the method comprising:

determining an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location upstream of a reductant injector to define a determined upstream NO_x amount;

determining an amount of NO_x present in the tailpipe at a second location downstream of the reductant injector to define a determined downstream NO_x amount;

subtracting the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value;

determining a cumulative difference based on the subtracted NO_x value;

determining whether the cumulative difference exceeds a control threshold;

setting a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold; and

setting the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

2. The method of claim **1**, further comprising determining whether to inject a reductant based on the selected upstream NO_x value and the determined downstream NO_x amount.

3. The method of claim **2**, further comprising injecting the reductant according to a predetermined injection model based on the selected upstream NO_x value and the determined downstream NO_x amount.

4. The method of claim **3**, further comprising determining the determined upstream NO_x amount as a mass of NO_x based on an upstream exhaust fluid flow rate at the first location, and determining the determined downstream NO_x amount as a mass of NO_x based on a downstream exhaust fluid flow rate at the second location.

5. The method of claim **4**, further comprising determining the cumulative difference by integrating the subtracted NO_x value with previous subtracted NO_x values obtained earlier in a key cycle.

6. The method of claim **5**, further comprising:

determining whether the cumulative difference exceeds a diagnostic threshold; and

activating a diagnostic signal if the cumulative difference exceeds the diagnostic threshold.

7. The method of claim **6**, further comprising determining the control threshold and the diagnostic threshold based on a maximum ammonia storage capacity of the selective catalytic reduction reductant delivery system.

8. The method of claim **7**, further comprising:

determining a maximum storage capacity multiplier based on the maximum ammonia storage capacity of selective catalytic reduction reductant delivery system;

determining the control threshold by multiplying the maximum storage capacity multiplier by a control constant; and

determining the diagnostic threshold by multiplying the maximum storage capacity multiplier by a diagnostic constant, wherein the diagnostic constant is greater than the control constant, and the diagnostic threshold is greater than the control threshold.

9. The method of claim 8, further comprising:
incrementing a counting device to define a count each time the selected upstream NO_x value is set as the predetermined model upstream NO_x amount; and
diagnosing a sensor error if the count exceeds a predetermined count threshold.

10. A selective catalytic reduction reductant injection control module including a processor and a non-volatile memory including a set of instructions which are configured to cause the processor to:
determine an amount of nitrogen oxide compounds (NO_x) present in a tailpipe at a first location upstream of a reductant injector to define a determined upstream NO_x amount;
determine an amount of NO_x present in the tailpipe at a second location downstream of the reductant injector to define a determined downstream NO_x amount;
subtract the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value;
determine a cumulative difference based on the subtracted NO_x value;
determine whether the cumulative difference exceeds a control threshold;
set a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold; and
set the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

11. The selective catalytic reduction reductant injection control module of claim 10, further configured to cause injection of the reductant according to a predetermined injection model based on the selected upstream NO_x value and the determined downstream NO_x amount.

12. The selective catalytic reduction reductant injection control module of claim 11, further configured to determine the determined upstream NO_x amount as a mass of NO_x based on an upstream exhaust fluid flow rate at the first location and to determine the determined downstream NO_x amount as a mass of NO_x based on a downstream exhaust fluid flow rate at the second location.

13. The selective catalytic reduction reductant injection control module of claim 12, further configured to determine the cumulative difference by integrating the subtracted NO_x value with previous subtracted NO_x values obtained earlier in a key cycle.

14. The selective catalytic reduction reductant injection control module of claim 13, further configured to:
determine whether the cumulative difference exceeds a diagnostic threshold; and
activate a diagnostic signal if the cumulative difference exceeds the diagnostic threshold.

15. The selective catalytic reduction reductant injection control module of claim 14, a maximum storage capacity multiplier being based on a maximum ammonia storage capacity of a selective catalytic reduction unit, the control threshold being based on multiplying the maximum storage capacity multiplier by a control constant, the diagnostic threshold being based on multiplying the maximum storage capacity multiplier by a diagnostic constant, wherein the diagnostic constant is greater than the control constant, and the diagnostic threshold is greater than the control threshold.

16. The selective catalytic reduction reductant injection control module of claim 15, further configured to:
increment a counting device to define a count each time the selected upstream NO_x value is set as the predetermined model upstream NO_x amount; and
diagnose a sensor error if the count exceeds a predetermined count threshold.

17. A vehicle system comprising:
a tailpipe assembly defining an exhaust conduit;
a selective catalytic reduction system including a reductant injector, the reductant injector configured to inject a reductant into fluid communication with the exhaust conduit of the tailpipe assembly;
an upstream NO_x sensor configured to measure nitrogen oxide compounds (NO_x) in an exhaust flow stream within the exhaust conduit, the upstream NO_x sensor being disposed in fluid communication with the exhaust conduit at a first location upstream of the selective catalytic reduction system;
a downstream NO_x sensor configured to measure NO_x in the exhaust flow stream within the exhaust conduit, the downstream NO_x sensor being disposed in fluid communication with the exhaust conduit at a second location downstream of the reductant injector; and
a reductant injection control module including a processor and a non-volatile memory including a set of instructions configured to cause the processor to:
determine an amount of NO_x present in the exhaust conduit based on an upstream signal from the upstream NO_x sensor to define a determined upstream NO_x amount;
determine an amount of NO_x present in the exhaust conduit based on a downstream signal from the downstream NO_x sensor to define a determined downstream NO_x amount;
subtract the determined upstream NO_x amount from the determined downstream NO_x amount to define a subtracted NO_x value;
determine a cumulative difference based on the subtracted NO_x value;
determine whether the cumulative difference exceeds a control threshold;
set a selected upstream NO_x value as a predetermined model upstream NO_x amount if the cumulative difference exceeds the control threshold; and
set the selected upstream NO_x value as the determined upstream NO_x amount if the cumulative difference does not exceed the control threshold.

18. The vehicle system of claim 17, the reductant injection control module being further configured to cause the reductant injector to inject the reductant according to a predetermined injection model based on the selected upstream NO_x value and the determined downstream NO_x amount.

19. The vehicle system of claim 18, the reductant injection control module being further configured to:
determine the determined upstream NO_x amount as a mass of NO_x based on an upstream exhaust fluid flow rate in the exhaust conduit at the first location;
determine the determined downstream NO_x amount as a mass of NO_x based on a downstream exhaust fluid flow rate in the exhaust conduit at the second location; and
determine the cumulative difference by integrating the subtracted NO_x value with previous subtracted NO_x values obtained earlier in a key cycle.

20. The vehicle system of claim **19**, the selective catalytic reduction system having a maximum ammonia storage capacity, the reductant injection control module being further configured to:

determine whether the cumulative difference exceeds a diagnostic threshold; and

activate a diagnostic signal if the cumulative difference exceeds the diagnostic threshold,

wherein a maximum storage capacity multiplier is based on the maximum ammonia storage capacity of the selective catalytic reduction system, the control threshold being based on multiplying the maximum storage capacity multiplier by a control constant, and the diagnostic threshold being based on multiplying the maximum storage capacity multiplier by a diagnostic constant, wherein the diagnostic constant is greater than the control constant, and the diagnostic threshold is greater than the control threshold.

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